Universidad de Costa Rica

Laboratorio 3

GPIO,ADC y comunicaciones

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1. Resumen

En este documento se encuentra el tercer laboratorio del curso, donde se desarrolla un multímetro de cuatro canales utilizando un Arduino UNO mediante el simulador *SimulIDE*. Donde se tiene un rango de tensiones entre los [-24V,24V] en DC o AC y se visualizan los valores en una pantalla LCD PCD8544. Con respecto al circuito diseñado, la regulación de voltaje se utilizaron amplificadores operacionales con el diseño que dan una salida en un rango de valores entre 0 al 5, luego los datos se exportan a un archivo plano con la información de las tensiones que poseen los canales. Como aspectos que se destacaron en el laboratorio, se tiene el diseño de circuitos analógicos para el control de las tensiones de entrada y su salida, además del uso de puertos virtuales para manipular la información que muestra el arduino.

2. Nota Teórica

En la presente sección se presenta la descripción sobre el microcontrolador utilizado, los componentes que conforman el hardware, así como cada periférico utilizado como los registros y las instrucciones programadas, además al final se muestra el diseño del circuito final.

2.1. Arduino UNO

El Arduino UNO es una placa que posee un microcontrolador de tipo ATmega328P, además de un ATmega16, puertos de alimentación y varios periféricos, que le permiten tener la capacidad de poder comunicarse con otros dispositivos. Algunas de las características que lo destacan, es de uso libre, es muy accesible para cualquier usuario además destaca su facilidad para poder utilizarlo. En la siguiente Figura 1 se muestra los pines que conforman a la placa Arduino UNO y su topología correspondiente.
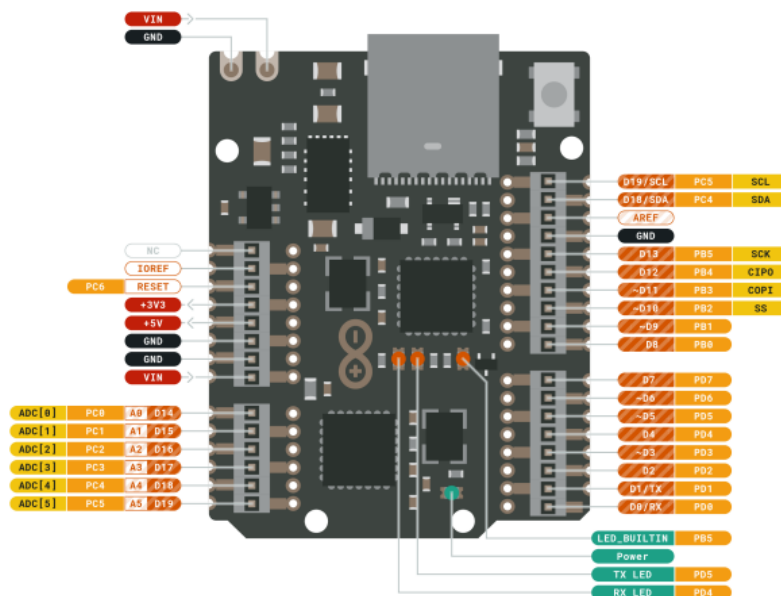

Figura 1: Pines de salida del Arduino Uno. Recuperado de [1]

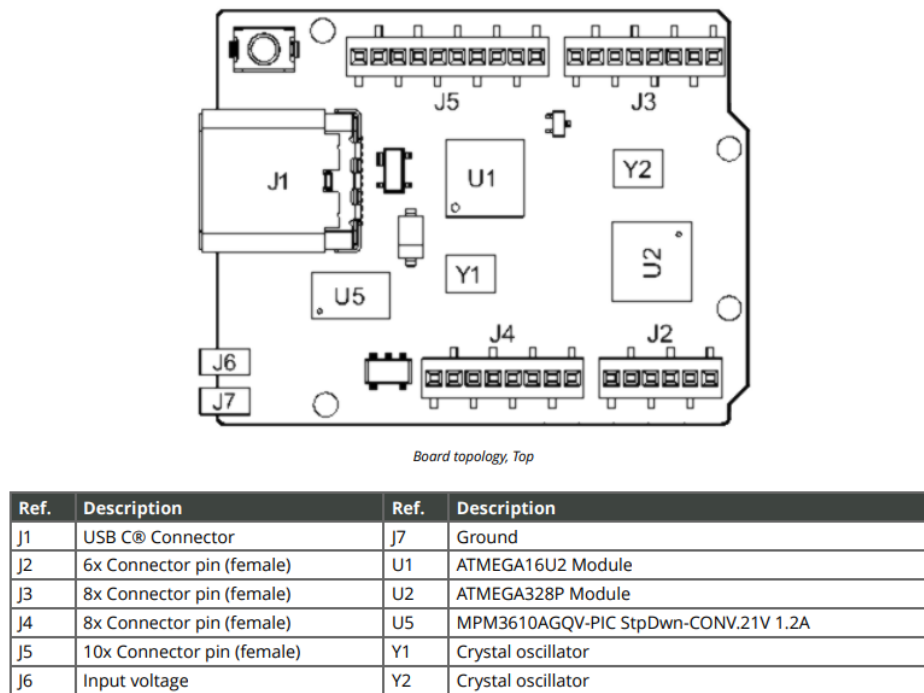La topología del Arduino UNO se muestra en la Figura 2

Board topology, Top

Ref.	Description	Ref.	Description
J1	USB C® Connector	J7	Ground
J2	6x Connector pin (female)	U1	ATMEGA16U2 Module
J3	8x Connector pin (female)	U2	ATMEGA328P Module
J4	8x Connector pin (female)	U5	MPM3610AGQV-PIC StpDwn-CONV.21V 1.2A
J5	10x Connector pin (female)	Y1	Crystal oscillator
J6	Input voltage	Y2	Crystal oscillator

Figura 2: Topología del Arduino UNO. Recuperado de [1]

Microcontrolador ATMega328P

Además se utilizó en el laboratorio un microcontrolador ATmega328P, como características según el fabricante [2] posee una memoria flash de 32KB, una SRAM 2KB y EEPROM de 1KB, también el microcontrolador es un CMOS de 8 bits basado en arquitectura RISC, tiene un total de 23 GPIOS, donde 8 de estos corresponden a canales con salida PWM que permite tener una salida analógica. Con respecto a los registros de propósito general posee 32 y también 3 contadores, donde uno es de 16 bits y el otro de 8 bits. Ahora, este microcontrolador opera entre los 1.8 a 5 V y la salida de sus pines llega hasta los 5 V [2]. En la Figura 3 se presenta la distribución de los pines, y en la Figura 4 que le sigue es su diagrama de bloques.
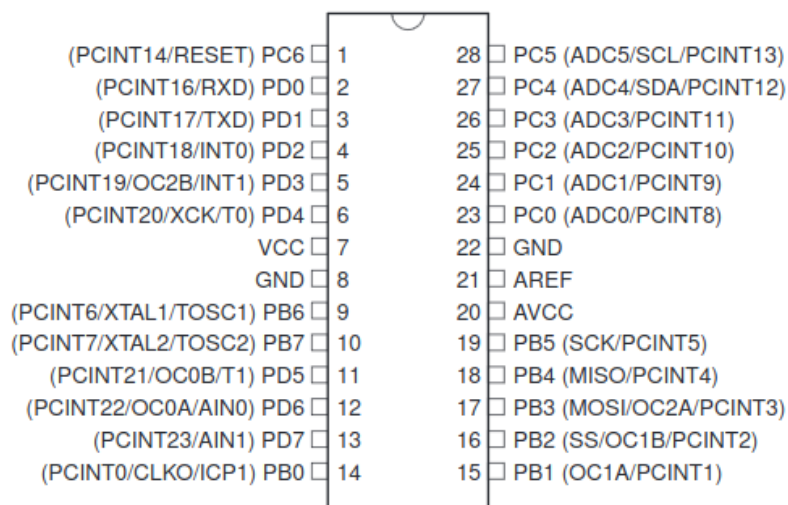

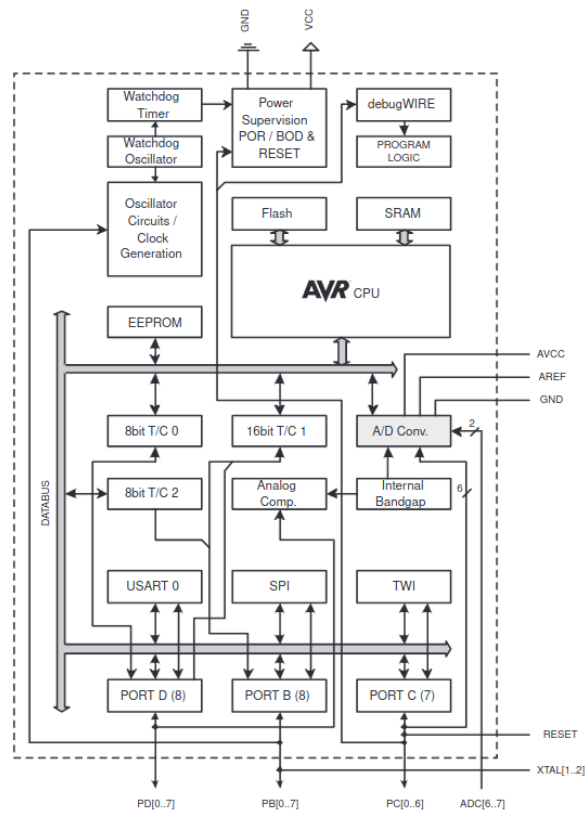Figura 3: Distribución de pines. Recuperado de [2]

2

Figura 4: Diagrama de bloques dell ATmega328P

2.2. Lista de Componentes

Ahora en la siguiente Tabla 1 se muestra la investigación realizada donde se tiene el precio por unidad y el lugar de venta de los diferentes componentes utilizados en el laboratorio 3. Cabe destacar que en la tabla se utilizan valores comerciales muy cercanos al del diseño de la simulación, la idea es poder tener un diseño más cercano a la realidad con valores cercanos que no se esperaría que cambie el comportamiento a lo esperado.

Tabla 1: Tabla 1: Lista de Componentes

Componente	Tipo	Cantidad	Precio por unidad	Lugar
Resistor	100 Ω	8	\$0,05	microJPM
Resistor	470 Ω	4	\$0,05	microJPM
Resistor	25 kΩ	4	\$0,05	microJPM
Resistor	1.2 kΩ	4	\$0,05	microJPM
Resistor	10 kΩ	4	\$0,05	microJPM
LED		4	\$0,55	microJPM
PCD8544		1	\$8,95	microJPM
Arduino UNO		1	\$49,95	microJPM
Amplificador	LM741	8	₡567	mouser electronics

Pantalla LCD PCD8544

Básicamente es una pantalla gráfica que puede ser utilizada en muchas aplicaciones, de forma original fue pensada como pantalla de un celular Nokia, se destaca por ser un controlador tipo CMOS de baja energía para LCD lo cual lo hace muy útil para diferentes aplicaciones [3]. En la siguiente Figura 5 se presenta la pantalla PCD8544.
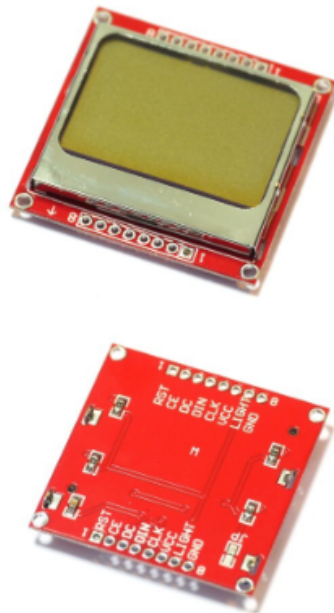

Figura 5: Pantalla LCD PCD8544. Recuperado de [3]

Amplificador Operacional

El amplificador operacional es un circuito integrado que permite poder realizar una gran variedad de circuitos, estos amplificadores están compuestos por muchos transistores internamente que controlan las corriente y tensiones [5]. A nivel comercial el amplificador más conocido es el 741 que se tiene en la siguiente Figura 6
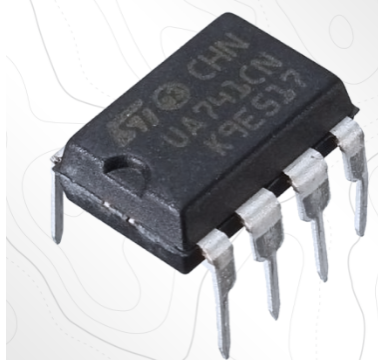

Figura 6: Amplificador Operacional 741. Recuperado de [5]

Como parte de sus especificaciones, puede recibir tensiones de entrada hasta los 15 V, tiene una disipación de potencia de 18 V, puede utilizarse para como protección de sobrecargas en la entrada o en su salida. En el caso del laboratorio tiene como función en reducir la tensión de entrada a una tensión entre valores de 0 a 5 V, para valores de entrada entre los -24 a 24 V, para especificaciones más detalladas se adjunta datos de fabricante en los apéndices.

2.3. Otros componentes electrónicos adicionales

- Resistores: Es un elemento que produce una resistencia al paso de corriente eléctrica, por lo que se puede determinar el paso de corriente si se conoce el valor de la tensión y de la resistencia, aplicando ley de ohm [3].

- LEDs: El LED tiene un funcionamiento simple, cuentas con dos terminales, el ánodo o cátodo, en el caso de existir una diferencia de tensión en el cual el cátodo es mayor a la tensión del ánodo, el elemento emitirá luz, en caso opuesto se mantiene apagado [3].

2.4. Diseño del Circuito

En relación al diseño del circuito primero se menciona la sección de hardware diseñada, primeramente se considera como entrada valores de tensión que pueden variar entre -24 a 24 V, entonces analizando determinamos en diseñar con ayuda de amplificadores operaciones dos circuitos que realicen la conversión de esas señales de entrada a valores entre los 0 a 5 V, considerando que las entradas pueden variar ya que existe la posibilidad de una entrada en AC. Ahora bien, la razón de dos circuitos fue porque uno puede recibir solo valores positivos y el otro solo negativos, en caso que reciban algún valor con signo que no corresponde tendrá un cero en su salida, por lo que en otras palabras ambos tienen el funcionamiento sea para positivos o negativos, entonces ya teniendo las salidas entre valores de 0 a 5 V para rangos de 0 a 24 V ó -24 a 0 V, se determinó luego implementar comparadores de forma que logre diferenciar los valores positivos o negativos.

2.4.1. Diseño de Amplificadores

Para el diseño de amplificadores operacionales, se considera la retroalimentación negativa para poder realizar corto circuito virtual(CCV) según lo aprendido en cursos anteriores. El primer circuito por analizar se presenta en la Figura 7 es también conocido como amplificador inversor
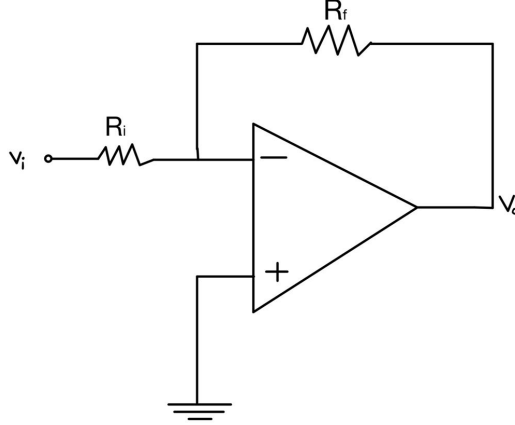

Figura 7: Circuito para entradas negativas

Por lo tanto, del anterior circuito V_i es la entrada de -24 a 0 V, es decir de los valores negativos, en caso de tener una entrada positiva en la entrada el circuito tendrá una salida de cero. Las ecuaciones que describen el circuito son:

Considerando la corriente I_1 que pasa por la resistencia R_F y la corriente I_2 que pasa por la resistencia R_i es la misma corriente se tiene que:

$$I_1 = I_2 \tag{1}$$

Aplicando corto circuito virtual:

$$V^- = V^+ = V_i \tag{2}$$

Ahora obteniendo las corrientes mediante diferencias de tensión:

$$I_2 = \frac{V^- - V_i}{R_i} \tag{3}$$

$$I_1 = \frac{V_O - V^-}{R_F} \tag{4}$$

Por lo tanto reemplazando con lo mencionado de corto circuito virtual producido por la retroalimentación negativa

$$I_2 = \frac{0 - V_i}{R_i} \tag{5}$$

$$I_1 = \frac{V_O - 0}{R_F} \tag{6}$$

Ahora con lo que se tiene de la ecuación 1 se sustituye con lo obtenido de las anteriores corrientes:

$$\frac{-V_i}{R_i} = \frac{V_O}{R_F} \tag{7}$$

Despejando la salida V_O

$$V_O = -Vi \cdot \frac{R_F}{R_i} \tag{8}$$

Por medio del anterior valor de salida dependiendo de los valores de resistencias y variando la tensión de entrada se puede obtener el rango de valores para la salida, lo anterior para valores de entrada negativos, como se observa el signo negativo logra obtener valores positivos del rango 0 a 5 V como salidas, considerando el rango de -24 a -1 de entradas.

Ahora, para el caso de las entradas positivas con el rango de 1 a 24 se diseña el siguiente circuito con un amplificador operacional y resistencias, similar al anterior pero la entrada no inversora se conecta a la entrada V_i.
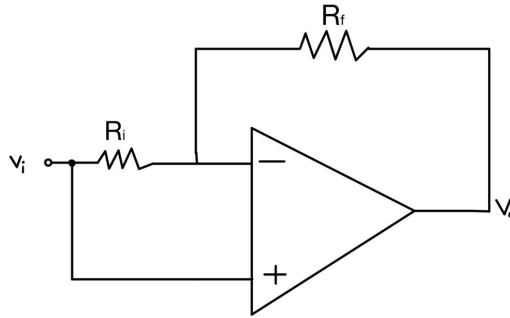

Figura 8: Circuito para entradas positivas

Del anterior amplificador pasa una corriente I_3 por R_F y otra I_4 por R_i. Ambas son la misma similar al circuito anterior. Ahora se busca conocer el valor de estas corrientes:

$$I_3 = \frac{V^- - V_O}{R_F} \tag{9}$$

$$I_4 = \frac{V_i - V^-}{R_i} \tag{10}$$

De forma que realizando lo mismo que antes debe de tener un valor de salida V_O

Entonces con lo anterior analizado, se presenta esta etapa donde a partir de las señales de tensiones entre los -24 a 24 V lo convierte a un rango entre 0 a 5 V.

En las siguientes Figuras 9 y 10 se tiene como tal el circuito para realizar esa conversión de la tensión de entrada a la salida, entonces en una se tiene una entrada negativa y la que le sigue es positiva, como resultado se obtienen los resultados esperados. Cabe destacar que se considera la primera etapa del circuito, entonces se crean tres más, por lo que representa cada multímetro, que en total son cuatro.
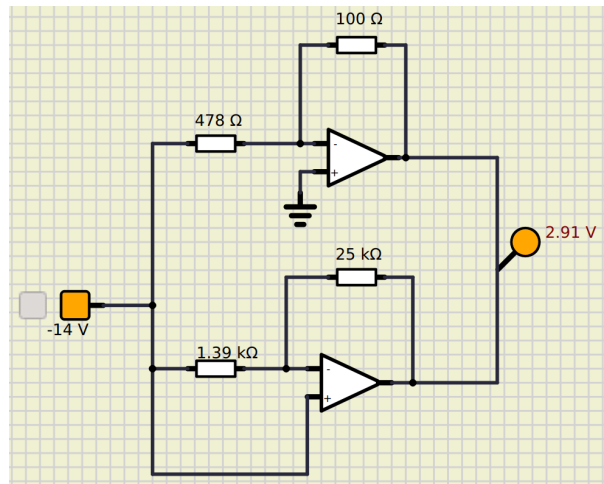
Figura 9: Circuito en Simulide para entradas negativas
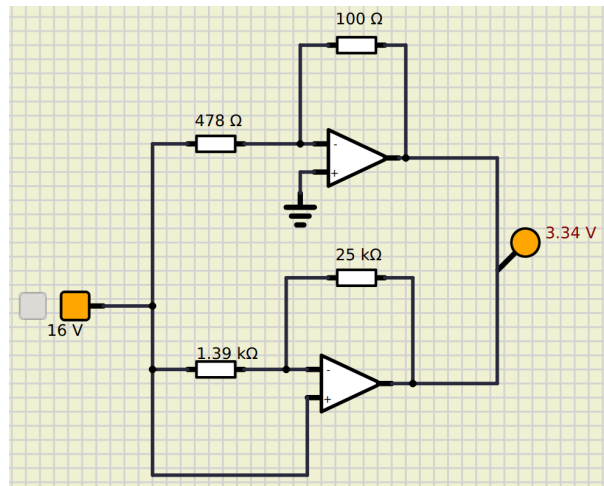
Figura 10: Circuito para entradas positivas

2.4.2. Etapa de verificación de signo

Para esta parte se realizó un circuito comparador, utilizando un amplificador operacional. Su tensión de entrada es la de las fuentes que generan las tensiones en un rango de [-24,24] V. Bajo condiciones óptimas, si las tensiones de ambos terminales de entrada son idénticas y no hay tensión diferencial, la salida no tendrá tensión. Sin embargo, si la entrada inversora tiene una tensión más alta que la no inversora, la salida mostrará una tensión negativa. En contraste, si la entrada inversora es menos positiva que la no inversora, la tensión de salida será positiva. El comparador está dado por la siguiente ecuación:

$$Vo = Av \cdot (V + -V-) \tag{11}$$

8
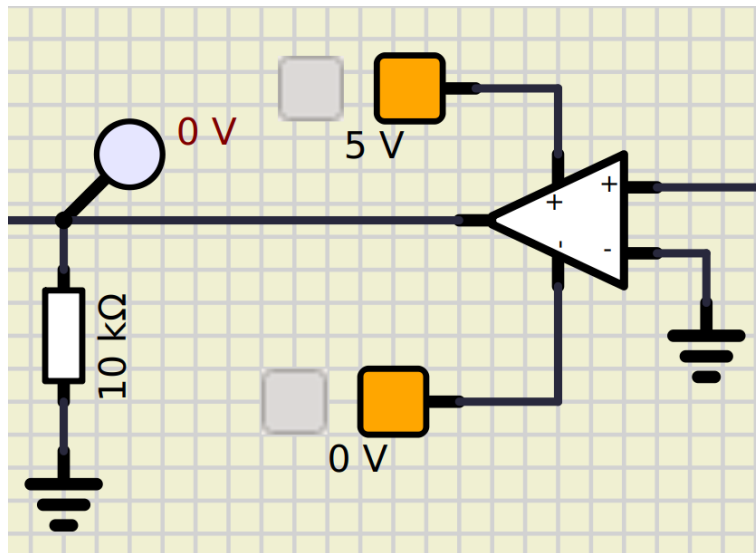
Figura 11: Circuito comparador para verificar signo

Como se puede observar en la figura 13 la entrada de la terminal negativa está conectada a tierra por lo que la tensión de salida la define la tensión de entrada. Si es un valor negativo la salida es cero y si es un valor positivo la salida es 5. Estas entradas son valores aceptables para las terminales de arduino.

2.5. Etapa de Leds de alarma

Se creó un sistema que alertara al usuario cuando había una tensión fuera del rango [-20,20]. Se escogieron LEDS amarillos para las alarmas y se puso un led por cada entrada de tensión. La hoja del fabricante adjunta en el anexo 1 indica una tensión normal normal de operación $V_f = 3$V. Para una corriente máxima de 20mA con una tensión de salida del arduino de 5V, la resistencia se calcula con la siguiente fórmula:

$$R = \frac{V_{cc} - V_f}{I_{cc}} = \frac{5 - 3}{20mA} = 100\Omega \tag{12}$$

Figura 12: Etapa de leds de alarma

2.6. Etapa de comunicación serial

Figura 13: Etapa de comunicación serial

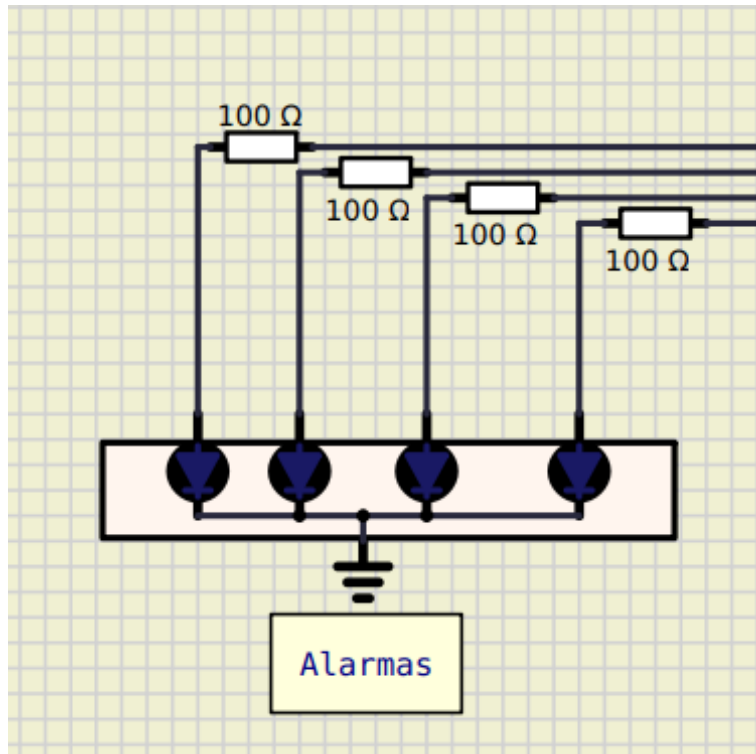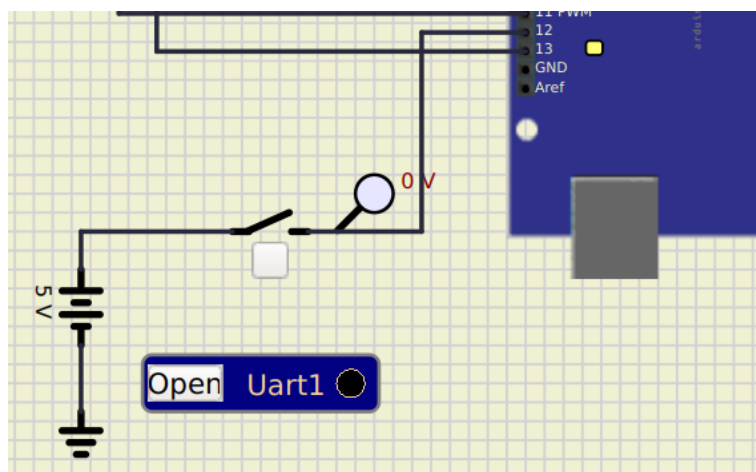Esta etapa se maneja por medio de un interruptor que permite la comunicación entre el arduino y la computadora, para que se transmitan los datos y se guarden en un archivo csv. Para esta parte se hace uso de los puertos virtuales y de la unidad de la UART, en las propiedades del componente se pone el path del puerto virtual asociado al arduino y en el script de python se declara el puerto que recibe los datos, como se puede observar a continuación:

```python
#!/usr/bin/python3
import serial
import time
import csv

#El nombre del archivo creado es salida.csv
fileName = "salida.csv"

# encabezado del archivo
header = "Primer Canal; Segundo Canal; Tercer Canal; Cuarto Canal\n"

ser = serial.Serial(
    port='/tmp/ttyS1',\
    baudrate=9600,\
    parity=serial.PARITY_NONE,\
    stopbits=serial.STOPBITS_ONE,\
    bytesize=serial.EIGHTBITS,\
    timeout=20\
    )


print("Archivo csv creado")

i = 0
valores = []
file = open(fileName, mode='w', newline='')
file.write(header)
datos = 120
counter = 0   # Contador de datos recibidos

while True:
    lines = ser.readline().decode().strip()
    valores.extend(lines.split(','))
    print(valores)

    if len(valores) >= 4:
        while len(valores) >= 4:
            linea = ";".join([str(valor) for valor in valores[:4]])
            file.write(linea)
            file.write("\n")
            valores = valores[4:]
            i += 4

    counter += 1
    if counter>= datos:
        break

ser.close()
file.close()
```

2.7. Diseño del voltímetro completo

Finalmente uniendo todas las etapas mencionadas anteriormente se presenta en la Figura 14 el circuito diseñado, donde a la derecha se encuentran las fuentes de alimentación al circuito que pueden ser AC o DC dependiendo de la selección en el switch, luego se conectan a los amplificadores que convierten la señal de entrada a un rango de valores entre 0 a 5 V, seguidamente en la parte superior los comparadores que se encargan en determinar el signo de las tensiones sea positivo o negativo y finalmente se conectan al Arduino UNO, como aspectos parte del diseño se tienen los LEDs al lado izquierdo del Arduino UNO, tal como se menciona anteriormente funcionan como alarma, también un switch que cuando esta abierto permite que los datos de las tensiones de los cuatro canales que se tienen en la pantalla PCD8544 y crea un archivo csv con los datos.
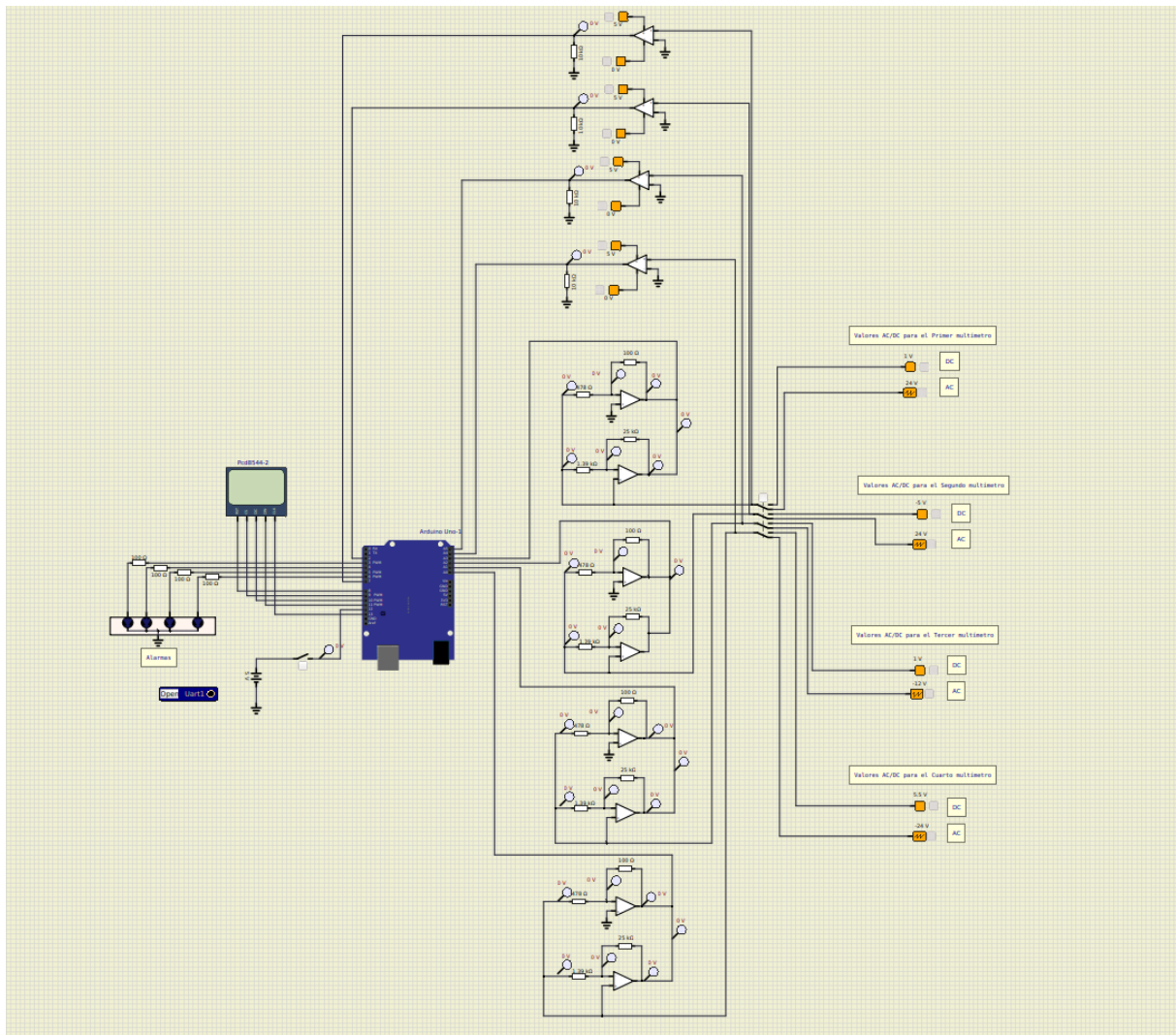
Figura 14: Circuito completo

3. Análisis de Resultados

En la presente sección de analiza de forma detallada lo que se desarrolló en el laboratorio 3.

3.1. Desarrollo del programa
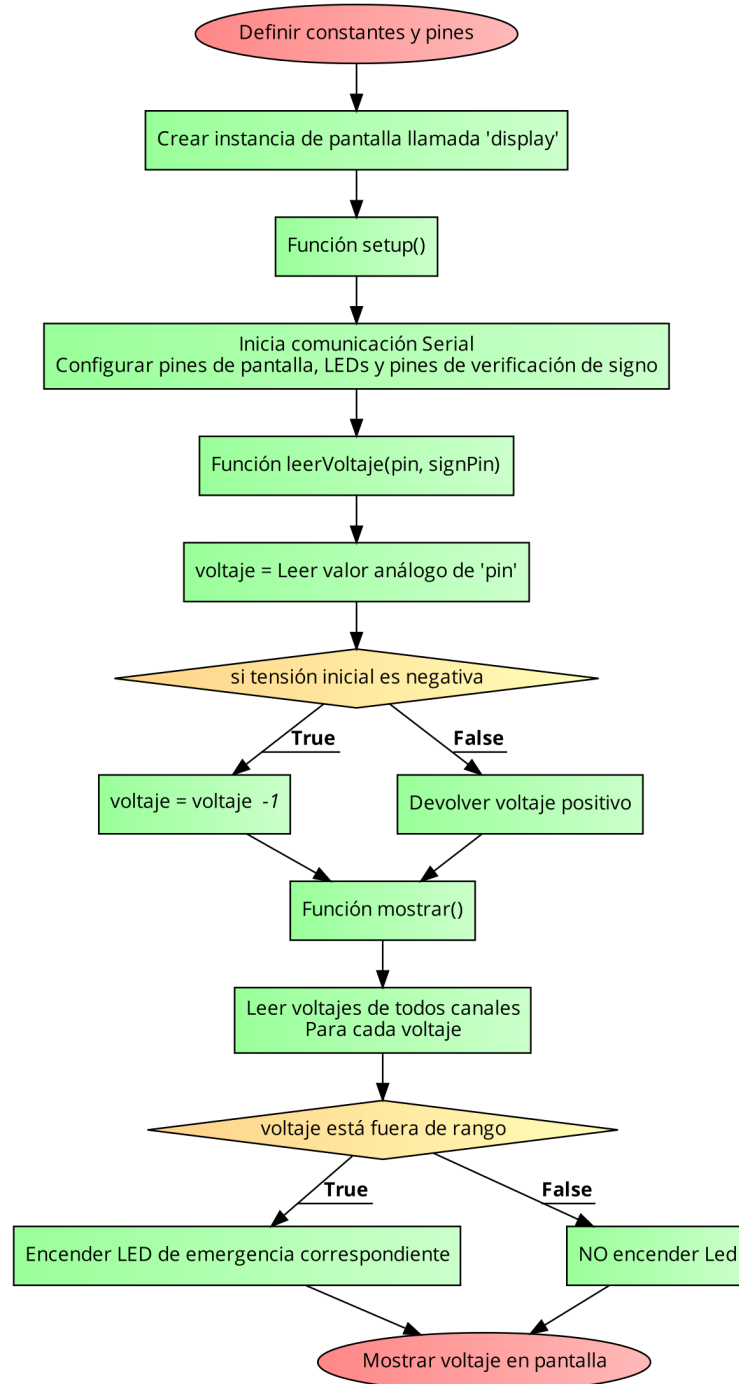
Figura 15: Diagrama del código implementado

Como se puede observar en la figura 15 el programa comienza definiendo las constantes y los pines. Se puede observar como se declaran pines que son conectados a la etapa de amplificadores comparadores que se encargan de determinar el signo de la entrada y se designan las entradas

de A0-A3 para la etapa de recorte de tensión, esta transforma la tensión del rango de [-24,24] en valores del 0 al 5.

```
1  // Conexiones del PCD8544
2  #define SCLK 13
3  #define DIN 11
4  #define DC 10
5  #define CS 9
6  #define RST 8
7
8  // Pines de verificacion de signo
9  #define SIGN_CHANNEL1 7
10 #define SIGN_CHANNEL2 2
11 #define SIGN_CHANNEL3 A5
12 #define SIGN_CHANNEL4 A4
13
14 // Pines para LEDs de alarma y entradas analogicas
15 #define LED1 3
16 #define LED2 4
17 #define LED3 5
18 #define LED4 6
19 #define CHANNEL1 A3
20 #define CHANNEL2 A2
21 #define CHANNEL3 A1
22 #define CHANNEL4 A0
23
24 #define TRIGGER_PIN 12 // Pin de entrada a verificar
25
```

Una vez definidos los pines se define la función setup, que se encarga de inciar la comunicación serial y los pines. Como se puede observar a continuación:

```
1      void setup() {
2
3    Serial.begin(9600); // Inicializa la comunicacion serial
4    pinMode(RST, OUTPUT);
5    pinMode(CS, OUTPUT);
6    pinMode(DC, OUTPUT);
7    pinMode(DIN, OUTPUT);
8    pinMode(SCLK, OUTPUT);
9
10
11   pinMode(LED1, OUTPUT);
12   pinMode(LED2, OUTPUT);
13   pinMode(LED3, OUTPUT);
14   pinMode(LED4, OUTPUT);
15
16   pinMode(SIGN_CHANNEL1, INPUT);
17   pinMode(SIGN_CHANNEL2, INPUT);
18   pinMode(SIGN_CHANNEL3, INPUT);
19   pinMode(SIGN_CHANNEL4, INPUT);
20
21   // Inicializa la pantalla y configura el contraste
22   display.begin();
23   display.setContrast(50);
24   display.clearDisplay();
25
26
27 }
```

Después sigue la parte del código que se encarga de leer el voltaje que fue reducido a un rango de [0,5]. analogRead(pin) lee un valor entre 0 y 1023 del pin analógico especificado. Este

valor se multiplica por (5.0 / 1023.0) para convertirlo en un voltaje entre 0 y 5 volts. Esto se basa en el hecho de que la entrada analógica de Arduino puede leer voltajes en ese rango y lo convierte en un valor entre 0 y 1023. Después se utiliza una conversión para obtener las tensiones originales de entrada y revisa las entradas del Arduino conectadas a la etapa de verificación de signo, si está en bajo se multiplica el valor por -1 como se ejemplifica en la figura 15. El código que se encarga de esto se presenta a continuación:

```
float readVoltage(int pin, int signPin) {
  // Lee el valor analogico y convierte a voltaje
  float voltage = analogRead(pin) * (5.0 / 1023.0);

  // Aplica la regla de tres para obtener el valor original
  // condiciones fueron consideradas a nivel analogico
  float originalValue = (voltage * 24)/5;

    // Verifica el pin de signo y ajusta el valor si es negativo
  if (digitalRead(signPin) == LOW) {   // Si es negativo
    originalValue *= -1;
  }

  return originalValue;
}
```

3.2. Pruebas del funcionamiento

Por último como parte del análisis de resultados se realizaron pruebas para comprobar el correcto funcionamiento del circuito. Primero se hicieron pruebas en DC con los valores en DC que se pueden observar en la figura 20
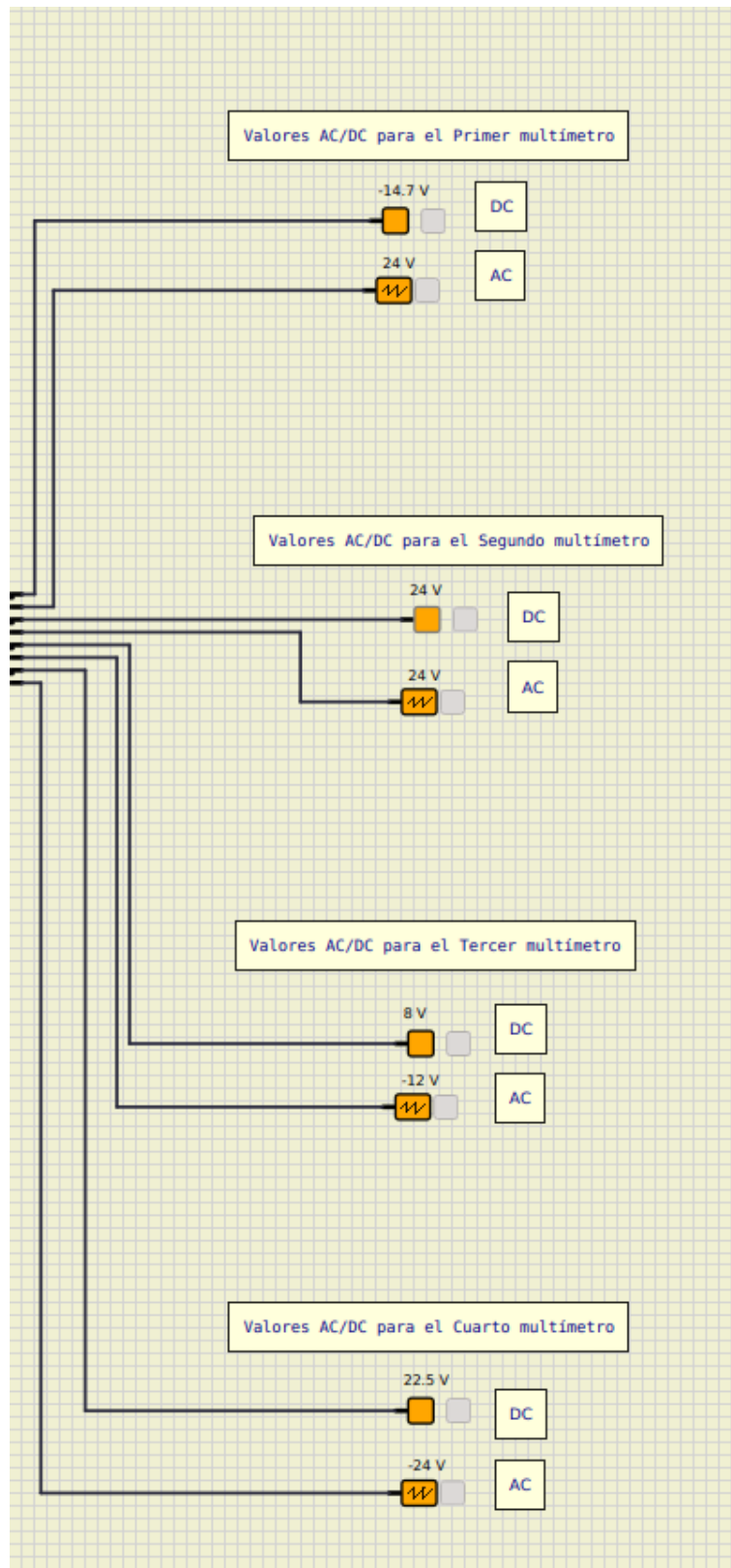

Figura 16: Pruebas con fuentes DC

De esta forma se obtienen resultados muy favorables, aceptando también valores decimales, como en el canal uno se observa una salida de -14.69 V lo cual difiere muy poco del valor original -14.7, como se puede observar en el siguiente cálculo del porcentaje de error:
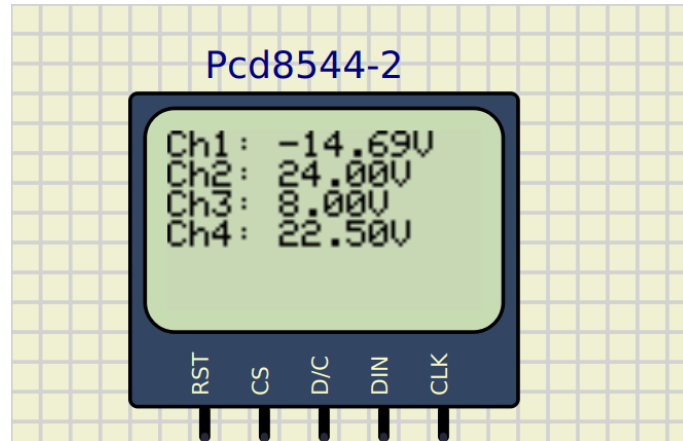
Figura 17: Resultados en pantalla con fuentes DC

$$\text{Porcentaje de Error} = \left| \frac{\text{Valor de salida} - \text{Valor original}}{\text{Valor original}} \right| \times 100\,\% \qquad (13)$$

Por lo que se tiene:

$$\text{Porcentaje de Error} = \left| \frac{\text{-14.69} - \text{-14.7}}{\text{-14.7}} \right| \times 100\,\% = 0{,}68\,\% \qquad (14)$$

De manera similar como se puede observar en la Figura 20 se configuraron también valores de entrada AC con la forma de una onda sinusoidal, por lo que el programa es capaz de convertir esos valores en una tensión reducida de 0 a 5, el cambio de DC a AC se hace por medio de switches, que cambian la fuente que entra al amplificador operacional. Como se puede observar en la figura 18 los valores son muy cercanos a los de las fuentes AC originales. Se procede a calcular el porcentaje de error con el valor de -23.34 utilizando la ecuación anterior, que da un valor bastante bajo también:

$$\text{Porcentaje de Error} = \left| \frac{\text{-23.34} - 24}{\text{-23.34}} \right| \times 100\,\% = 2{,}75\,\% \qquad (15)$$
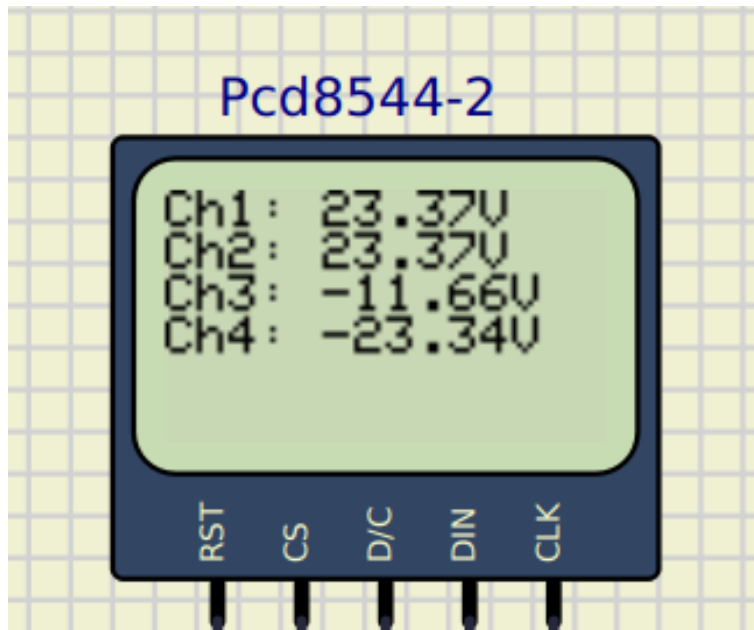
Figura 18: Resultados en pantalla con fuentes AC

Después por medio del switch explicado en la etapa de transmisión serial se logró comunicación entre la computadora y el microcontrolador, esto resultados se obtuvieron tanto para DC como AC y se pueden observar a continuación:

Figura 19: Resultado en terminal de transmisión serial con fuente AC

Figura 20: Resultado en terminal de transmisión serial con fuente DC

3.3. Repositorio Git

El repositorio de Github que contiene los archivos que muestran lo realizado se encuentra en el link: `https://github.com/SofiVillalta29/Laboratorio_De_Microcontroladores/tree/main`

4. Conclusiones y Recomendaciones

- Es muy importante para este laboratorio entender bien como funciona el IDE de Arduino, debido a que se utiliza para compilar el código y que se genere el archivo .hex que se carga en Simulide. Por lo tanto configurar bien los puertos virtuales para poder generar comunicación entre el arduino y la computadora.

- Durante el desarrollo del laboratorio se destaca el uso de electrónica analógica en este caso amplificadores para poder realizar la conversión del rango de valores a lo solicitado en el enunciado, aplicando conceptos importantes aprendidos en cursos anteriores y combinándolos con los del curso actual.

- El uso de amplificadores operacionales para hacer comparadores de voltaje es una técnica útil y sencilla para poder saber el signo de una tensión de entrada y así poder manejar con el código los casos para los distintos valores.

Referencias

[1] Arduino UNO R3. Product reference manual. Disponible en: `https://docs.arduino.cc/resources/datasheets/ABX00062-datasheet.pdf`

[2] Atmel 8-bit avr microcontrollers: Atmega3289. Disponible en: `https://pdf1.alldatasheet.com/datasheet-pdf/view/241077/ATMEL/ATMEGA328P.html`

[3] Espruino. PCD8544 LCD(Nokia 5110). Disponible en: `https://www.espruino.com/PCD8544`

[4] Componentes básicos en la electrónica. (s.f). Monografías.com. Disponible en: `https://www.monografias.com/trabajos107/componentes-basicos-electronica/componentes-basicos-electronica`

[5] A. Castillo.(2023). *¿Qué es un amplificador operacional?*. Disponible en: https://blog.330ohms.com/2020/07/27/que-es-un-amplificador-operacional/

5. Apéndice
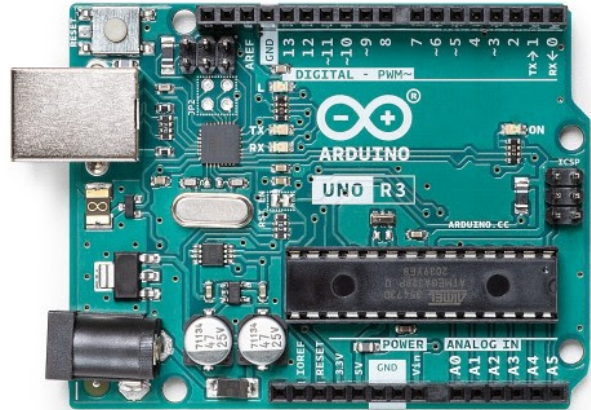
Description

The Arduino UNO R3 is the perfect board to get familiar with electronics and coding. This versatile development board is equipped with the well-known ATmega328P and the ATMega 16U2 Processor.
This board will give you a great first experience within the world of Arduino.

Target areas:

Maker, introduction, industries

Features

- **ATMega328P** Processor
    - **Memory**
        - AVR CPU at up to 16 MHz
        - 32KB Flash
        - 2KB SRAM
        - 1KB EEPROM
    - **Security**
        - Power On Reset (POR)
        - Brown Out Detection (BOD)
    - **Peripherals**
        - 2x 8-bit Timer/Counter with a dedicated period register and compare channels
        - 1x 16-bit Timer/Counter with a dedicated period register, input capture and compare channels
        - 1x USART with fractional baud rate generator and start-of-frame detection
        - 1x controller/peripheral Serial Peripheral Interface (SPI)
        - 1x Dual mode controller/peripheral I2C
        - 1x Analog Comparator (AC) with a scalable reference input
        - Watchdog Timer with separate on-chip oscillator
        - Six PWM channels
        - Interrupt and wake-up on pin change
    - **ATMega16U2 Processor**
        - 8-bit AVR® RISC-based microcontroller
    - **Memory**
        - 16 KB ISP Flash
        - 512B EEPROM
        - 512B SRAM
        - debugWIRE interface for on-chip debugging and programming
    - **Power**
        - 2.7-5.5 volts

CONTENTS

1 The Board

1.1 Application Examples

The UNO board is the flagship product of Arduino. Regardless if you are new to the world of electronics or will use the UNO as a tool for education purposes or industry-related tasks, the UNO is likely to meet your needs.

First entry to electronics: If this is your first project within coding and electronics, get started with our most used and documented board; Arduino UNO. It is equipped with the well-known ATmega328P processor, 14 digital input/output pins, 6 analog inputs, USB connections, ICSP header and reset button. This board includes everything you will need for a great first experience with Arduino.

Industry-standard development board: Using the Arduino UNO R3 board in industries, there are a range of companies using the UNO board as the brain for their PLC's.

Education purposes: Although the UNO R3 board has been with us for about ten years, it is still widely used for various education purposes and scientific projects. The board's high standard and top quality performance makes it a great resource to capture real time from sensors and to trigger complex laboratory equipment to mention a few examples.

1.2 Related Products

- Starter Kit
- Arduino UNO R4 Minima
- Arduino UNO R4 WiFi
- Tinkerkit Braccio Robot

2 Ratings

2.1 Recommended Operating Conditions

Symbol	Description	Min	Max
	Conservative thermal limits for the whole board:	-40 °C (-40°F)	85 °C (185°F)

NOTE: In extreme temperatures, EEPROM, voltage regulator, and the crystal oscillator, might not work as expected.

2.2 Power Consumption

Symbol	Description	Min	Typ	Max	Unit
VINMax	Maximum input voltage from VIN pad	6	-	20	V
VUSBMax	Maximum input voltage from USB connector		-	5.5	V
PMax	Maximum Power Consumption	-	-	xx	mA

3 Functional Overview

3.1 Board Topology

Top view
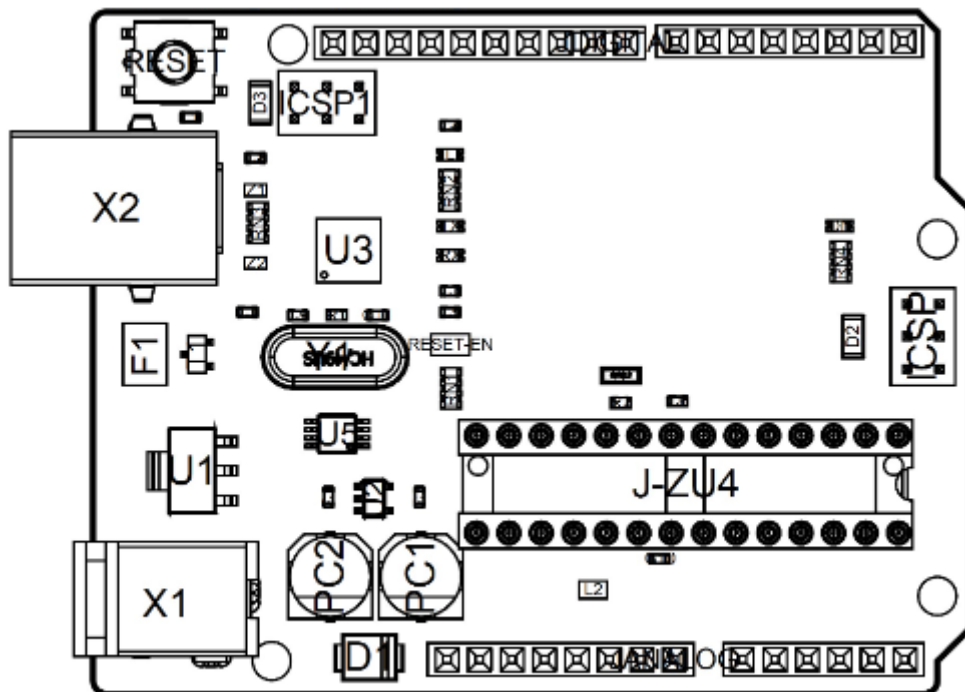
Board topology

Ref.	Description	Ref.	Description
X1	Power jack 2.1x5.5mm	U1	SPX1117M3-L-5 Regulator
X2	USB B Connector	U3	ATMEGA16U2 Module
PC1	EEE-1EA470WP 25V SMD Capacitor	U5	LMV358LIST-A.9 IC
PC2	EEE-1EA470WP 25V SMD Capacitor	F1	Chip Capacitor, High Density
D1	CGRA4007-G Rectifier	ICSP	Pin header connector (through hole 6)
J-ZU4	ATMEGA328P Module	ICSP1	Pin header connector (through hole 6)
Y1	ECS-160-20-4X-DU Oscillator		

3.2 Processor

The Main Processor is a ATmega328P running at up to 20 MHz. Most of its pins are connected to the external headers, however some are reserved for internal communication with the USB Bridge coprocessor.

3.3 Power Tree
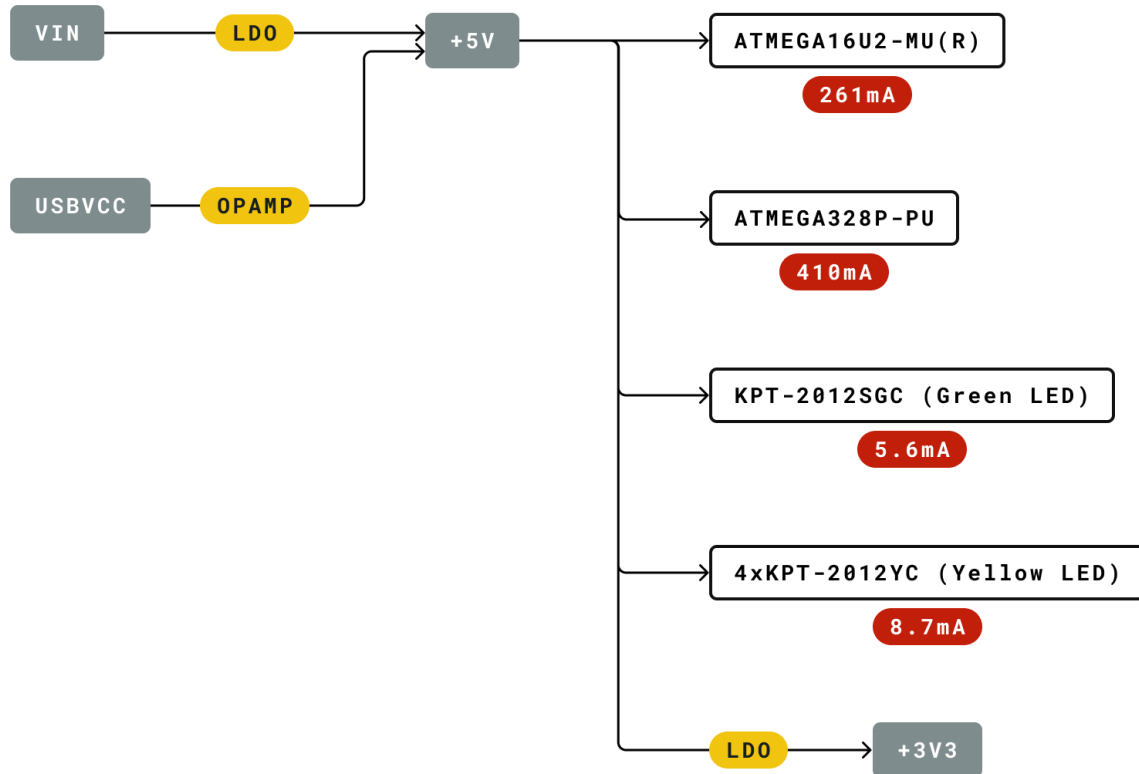
Legend:

◻ Component   ● Power I/O   ● Conversion Type

● Max Current   ● Voltage Range

Power tree

4 Board Operation

4.1 Getting Started - IDE

If you want to program your Arduino UNO R3 while offline you need to install the Arduino Desktop IDE [1] To connect the Arduino UNO to your computer, you'll need a USB-B cable. This also provides power to the board, as indicated by the LED.

4.2 Getting Started - Arduino Web Editor

All Arduino boards, including this one, work out-of-the-box on the Arduino Web Editor [2], by just installing a simple plugin.

The Arduino Web Editor is hosted online, therefore it will always be up-to-date with the latest features and support for all boards. Follow **[3]** to start coding on the browser and upload your sketches onto your board.

4.3 Sample Sketches

Sample sketches for the Arduino UNO R3 can be found either in the "Examples" menu in the Arduino IDE or in the "Documentation" section of the Arduino website [4]

4.4 Online Resources

Now that you have gone through the basics of what you can do with the board you can explore the endless possibilities it provides by checking exciting projects on Arduino Project Hub **[5]**, the Arduino Library Reference **[6]** and the online Arduino store **[7]** where you will be able to complement your board with sensors, actuators and more.

5 Connector Pinouts
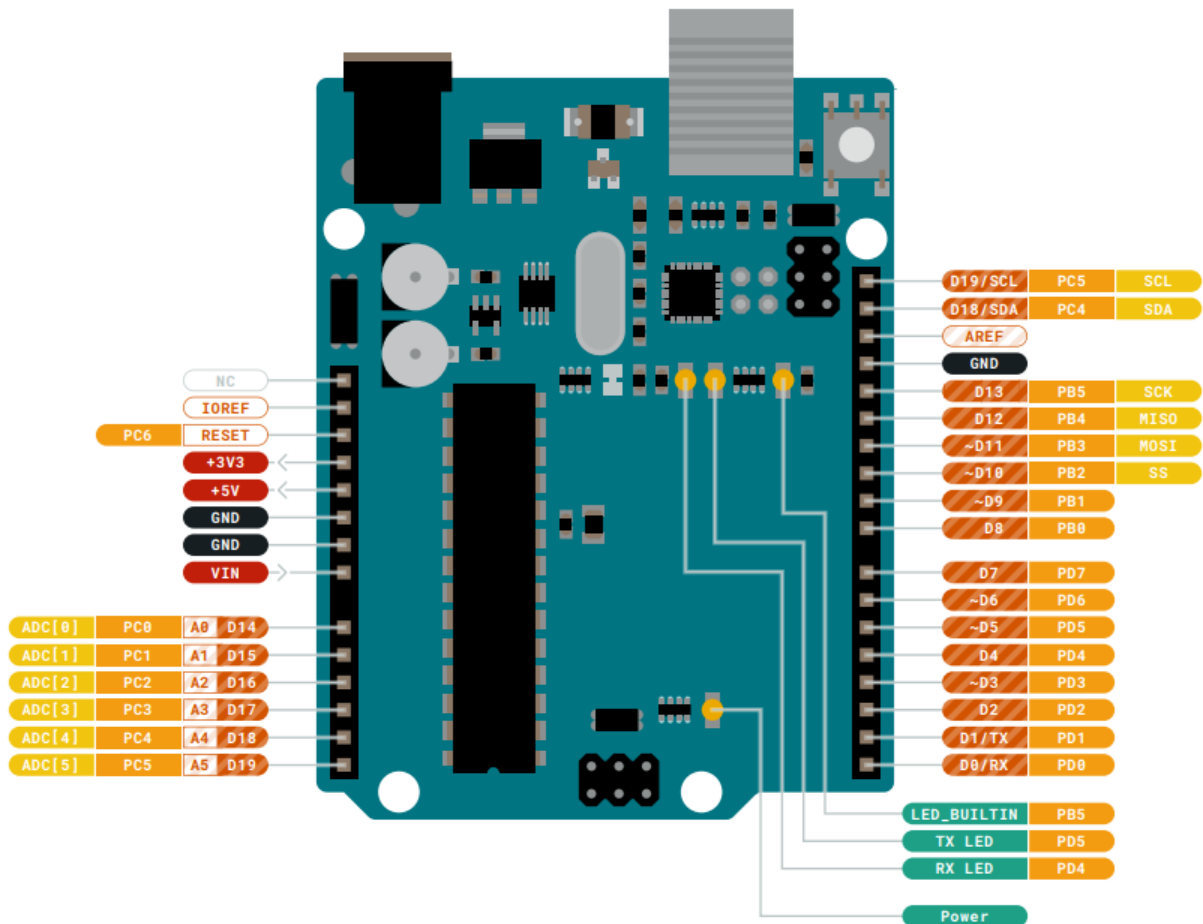
Pinout

5.1 JANALOG

Pin	Function	Type	Description
1	NC	NC	Not connected
2	IOREF	IOREF	Reference for digital logic V - connected to 5V
3	Reset	Reset	Reset
4	+3V3	Power	+3V3 Power Rail
5	+5V	Power	+5V Power Rail
6	GND	Power	Ground
7	GND	Power	Ground
8	VIN	Power	Voltage Input
9	A0	Analog/GPIO	Analog input 0 /GPIO
10	A1	Analog/GPIO	Analog input 1 /GPIO
11	A2	Analog/GPIO	Analog input 2 /GPIO
12	A3	Analog/GPIO	Analog input 3 /GPIO
13	A4/SDA	Analog input/I2C	Analog input 4/I2C Data line
14	A5/SCL	Analog input/I2C	Analog input 5/I2C Clock line

5.2 JDIGITAL

Pin	Function	Type	Description
1	D0	Digital/GPIO	Digital pin 0/GPIO
2	D1	Digital/GPIO	Digital pin 1/GPIO
3	D2	Digital/GPIO	Digital pin 2/GPIO
4	D3	Digital/GPIO	Digital pin 3/GPIO
5	D4	Digital/GPIO	Digital pin 4/GPIO
6	D5	Digital/GPIO	Digital pin 5/GPIO
7	D6	Digital/GPIO	Digital pin 6/GPIO
8	D7	Digital/GPIO	Digital pin 7/GPIO
9	D8	Digital/GPIO	Digital pin 8/GPIO
10	D9	Digital/GPIO	Digital pin 9/GPIO
11	SS	Digital	SPI Chip Select
12	MOSI	Digital	SPI1 Main Out Secondary In
13	MISO	Digital	SPI Main In Secondary Out
14	SCK	Digital	SPI serial clock output
15	GND	Power	Ground
16	AREF	Digital	Analog reference voltage
17	A4/SD4	Digital	Analog input 4/I2C Data line (duplicated)
18	A5/SD5	Digital	Analog input 5/I2C Clock line (duplicated)

5.3 Mechanical Information

5.4 Board Outline & Mounting Holes

Board outline
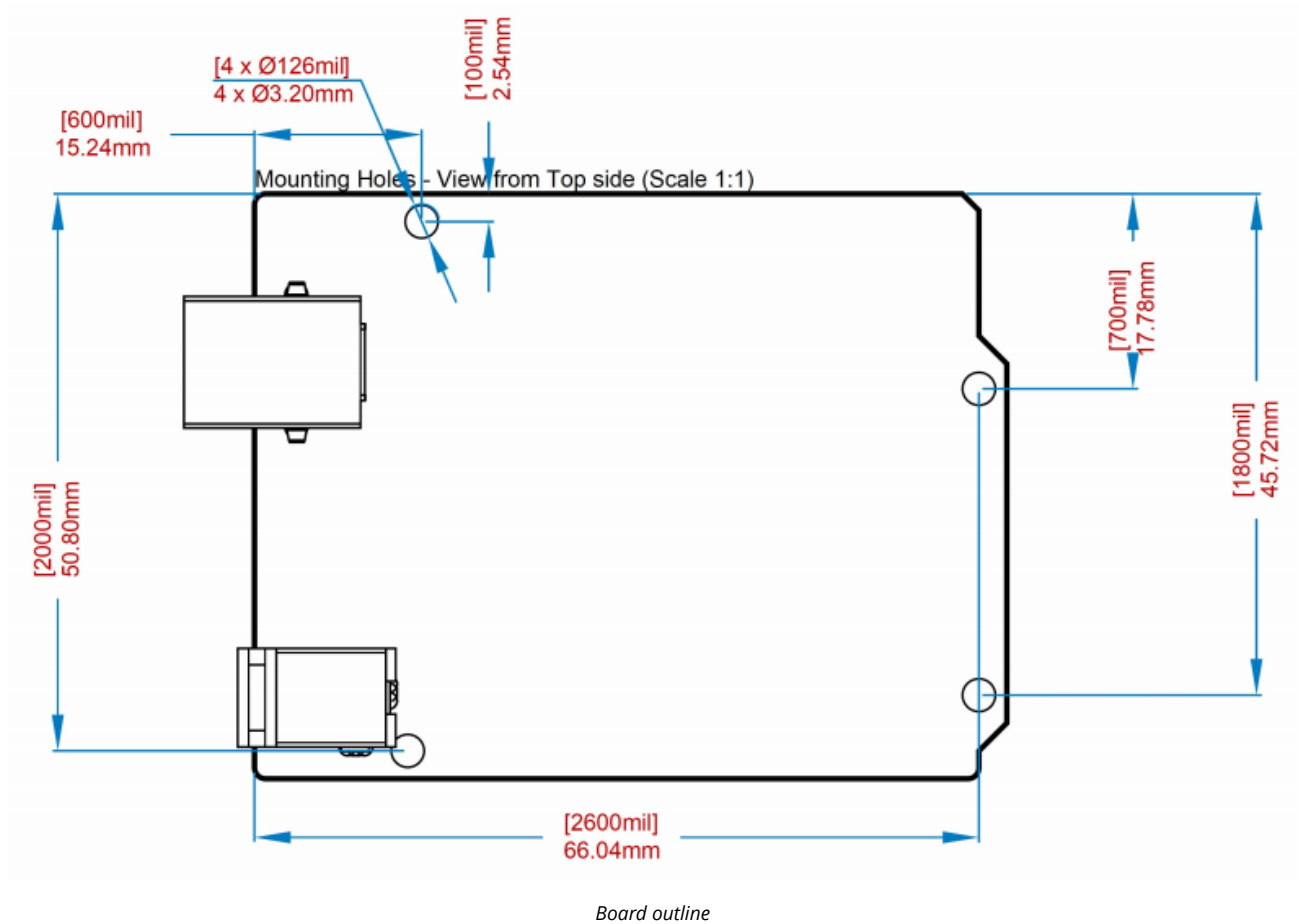
6 Certifications

6.1 Declaration of Conformity CE DoC (EU)

We declare under our sole responsibility that the products above are in conformity with the essential requirements of the following EU Directives and therefore qualify for free movement within markets comprising the European Union (EU) and European Economic Area (EEA).

ROHS 2 Directive 2011/65/EU	
Conforms to:	EN50581:2012
Directive 2014/35/EU. (LVD)	
Conforms to:	EN 60950-1:2006/A11:2009/A1:2010/A12:2011/AC:2011
Directive 2004/40/EC & 2008/46/EC & 2013/35/EU, EMF	
Conforms to:	EN 62311:2008

6.2 Declaration of Conformity to EU RoHS & REACH 211 01/19/2021

Arduino boards are in compliance with RoHS 2 Directive 2011/65/EU of the European Parliament and RoHS 3 Directive 2015/863/EU of the Council of 4 June 2015 on the restriction of the use of certain hazardous substances in electrical and electronic equipment.

Substance	Maximum limit (ppm)
Lead (Pb)	1000
Cadmium (Cd)	100
Mercury (Hg)	1000
Hexavalent Chromium (Cr6+)	1000
Poly Brominated Biphenyls (PBB)	1000
Poly Brominated Diphenyl ethers (PBDE)	1000
Bis(2-Ethylhexyl} phthalate (DEHP)	1000
Benzyl butyl phthalate (BBP)	1000
Dibutyl phthalate (DBP)	1000
Diisobutyl phthalate (DIBP)	1000

Exemptions: No exemptions are claimed.

Arduino Boards are fully compliant with the related requirements of European Union Regulation (EC) 1907 /2006 concerning the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH). We declare none of the SVHCs (https://echa.europa.eu/web/guest/candidate-list-table), the Candidate List of Substances of Very High Concern for authorization currently released by ECHA, is present in all products (and also package) in quantities totaling in a concentration equal or above 0.1%. To the best of our knowledge, we also declare that our products do not contain any of the substances listed on the "Authorization List" (Annex XIV of the REACH regulations) and Substances of Very High Concern (SVHC) in any significant amounts as specified by the Annex XVII of Candidate list published by ECHA (European Chemical Agency) 1907 /2006/EC.

6.3 Conflict Minerals Declaration

As a global supplier of electronic and electrical components, Arduino is aware of our obligations with regards to laws and regulations regarding Conflict Minerals, specifically the Dodd-Frank Wall Street Reform and Consumer Protection Act, Section 1502. Arduino does not directly source or process conflict minerals such as Tin, Tantalum, Tungsten, or Gold. Conflict minerals are contained in our products in the form of solder, or as a component in metal alloys. As part of our reasonable due diligence Arduino has contacted component suppliers within our supply chain to verify their continued compliance with the regulations. Based on the information received thus far we declare that our products contain Conflict Minerals sourced from conflict-free areas.

7 FCC Caution

Any Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions:

(1) This device may not cause harmful interference

(2) this device must accept any interference received, including interference that may cause undesired operation.

FCC RF Radiation Exposure Statement:

1. This Transmitter must not be co-located or operating in conjunction with any other antenna or transmitter.

2. This equipment complies with RF radiation exposure limits set forth for an uncontrolled environment.

3. This equipment should be installed and operated with minimum distance 20cm between the radiator & your body.

English: User manuals for license-exempt radio apparatus shall contain the following or equivalent notice in a conspicuous location in the user manual or alternatively on the device or both. This device complies with Industry Canada license-exempt RSS standard(s). Operation is subject to the following two conditions:

(1) this device may not cause interference

(2) this device must accept any interference, including interference that may cause undesired operation of the device.

French: Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes :

(1) l' appareil nedoit pas produire de brouillage

(2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

IC SAR Warning:

English This equipment should be installed and operated with minimum distance 20 cm between the radiator and your body.

French: Lors de l' installation et de l' exploitation de ce dispositif, la distance entre le radiateur et le corps est d 'au moins 20 cm.

Important: The operating temperature of the EUT can't exceed 85℃ and shouldn't be lower than -40℃.

Hereby, Arduino S.r.l. declares that this product is in compliance with essential requirements and other relevant provisions of Directive 2014/53/EU. This product is allowed to be used in all EU member states.

8 Company Information

Company name	Arduino S.r.l
Company Address	Via Andrea Appiani 25 20900 MONZA Italy

9 Reference Documentation

Reference	Link
Arduino IDE (Desktop)	https://www.arduino.cc/en/Main/Software
Arduino IDE (Cloud)	https://create.arduino.cc/editor
Cloud IDE Getting Started	https://create.arduino.cc/projecthub/Arduino_Genuino/getting-started-with-arduino-web-editor-4b3e4a
Arduino Website	https://www.arduino.cc/
Project Hub	https://create.arduino.cc/projecthub?by=part&part_id=11332&sort=trending
Library Reference	https://www.arduino.cc/reference/en/
Online Store	https://store.arduino.cc/

10 Revision History

Date	Revision	Changes
26/07/2023	2	General Update
06/2021	1	Datasheet release

TEXAS INSTRUMENTS

LM741 Operational Amplifier

1 Features

- Overload Protection on the Input and Output
- No Latch-Up When the Common-Mode Range is Exceeded

2 Applications

- Comparators
- Multivibrators
- DC Amplifiers
- Summing Amplifiers
- Integrator or Differentiators
- Active Filters

3 Description

The LM741 series are general-purpose operational amplifiers which feature improved performance over industry standards like the LM709. They are direct, plug-in replacements for the 709C, LM201, MC1439, and 748 in most applications.

The amplifiers offer many features which make their application nearly foolproof: overload protection on the input and output, no latch-up when the common-mode range is exceeded, as well as freedom from oscillations.

The LM741C is identical to the LM741 and LM741A except that the LM741C has their performance ensured over a 0°C to +70°C temperature range, instead of −55°C to +125°C.

Device Information[1]

PART NUMBER	PACKAGE	BODY SIZE (NOM)
LM741	TO-99 (8)	9.08 mm × 9.08 mm
	CDIP (8)	10.16 mm × 6.502 mm
	PDIP (8)	9.81 mm × 6.35 mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.
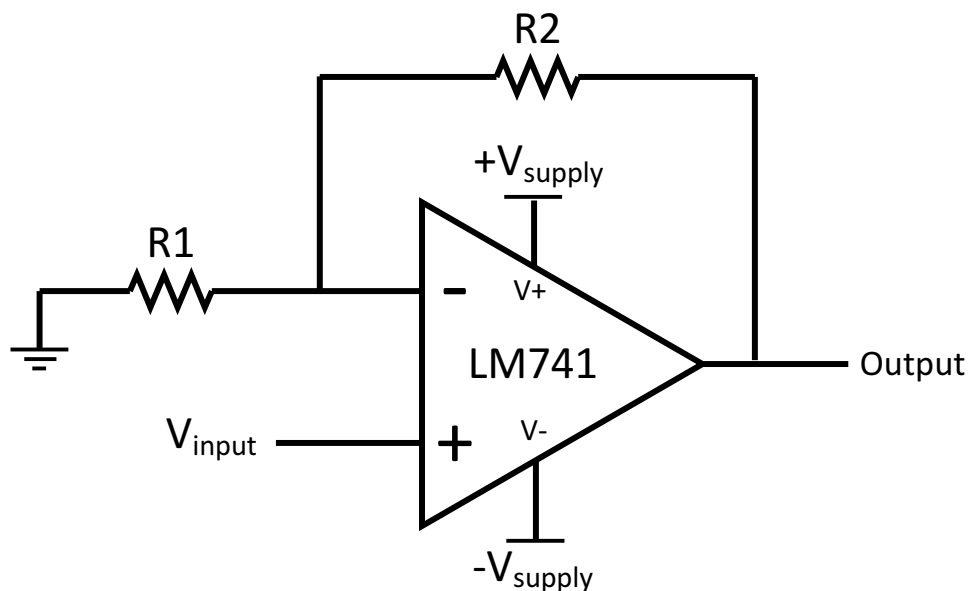
Typical Application

Table of Contents

4 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision C (October 2004) to Revision D   **Page**

- Added *Applications* section, *Pin Configuration and Functions* section, *ESD Ratings* table, *Feature Description* section, *Device Functional Modes*, *Application and Implementation* section, *Power Supply Recommendations* section, *Layout* section, *Device and Documentation Support* section, and *Mechanical, Packaging, and Orderable Information* section 1
- Removed NAD 10-Pin CLGA pinout 3
- Removed obselete M (S0-8) package from the data sheet 4
- Added recommended operating supply voltage spec 4
- Added recommended operating temperature spec 4

Changes from Revision C (March 2013) to Revision D   **Page**

- Added *Applications* section, *Pin Configuration and Functions* section, *ESD Ratings* table, *Feature Description* section, *Device Functional Modes*, *Application and Implementation* section, *Power Supply Recommendations* section, *Layout* section, *Device and Documentation Support* section, and *Mechanical, Packaging, and Orderable Information* section 1
- Removed NAD 10-Pin CLGA pinout 3
- Removed obselete M (S0-8) package from the data sheet 4
- Added recommended operating supply voltage spec 4
- Added recommended operating temperature spec 4

Product Folder Links: *LM741*

5 Pin Configuration and Functions

LMC Package
8-Pin TO-99
Top View
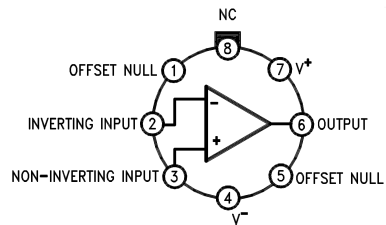
LM741H is available per JM38510/10101

NAB Package
8-Pin CDIP or PDIP
Top View
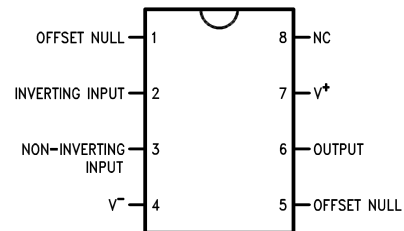
Pin Functions

PIN		I/O	DESCRIPTION
NAME	NO.		
INVERTING INPUT	2	I	Inverting signal input
NC	8	N/A	No Connect, should be left floating
NONINVERTING INPUT	3	I	Noninverting signal input
OFFSET NULL	1, 5	I	Offset null pin used to eliminate the offset voltage and balance the input voltages.
OFFSET NULL			
OUTPUT	6	O	Amplified signal output
V+	7	I	Positive supply voltage
V–	4	I	Negative supply voltage

Submit Documentation Feedback   3

Product Folder Links: *LM741*

6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted) [1] [2] [3]

		MIN	MAX	UNIT
Supply voltage	LM741, LM741A		±22	V
	LM741C		±18	
Power dissipation [4]			500	mW
Differential input voltage			±30	V
Input voltage [5]			±15	V
Output short circuit duration		Continuous		
Operating temperature	LM741, LM741A	−50	125	°C
	LM741C	0	70	
Junction temperature	LM741, LM741A		150	°C
	LM741C		100	
Soldering information	PDIP package (10 seconds)		260	°C
	CDIP or TO-99 package (10 seconds)		300	°C
Storage temperature, T_{stg}		−65	150	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) For military specifications see RETS741X for LM741 and RETS741AX for LM741A.
(3) If Military/Aerospace specified devices are required, please contact the TI Sales Office/Distributors for availability and specifications.
(4) For operation at elevated temperatures, these devices must be derated based on thermal resistance, and T_j max. (listed under "Absolute Maximum Ratings"). $T_j = T_A + (\theta_{jA} P_D)$.
(5) For supply voltages less than ±15 V, the absolute maximum input voltage is equal to the supply voltage.

6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human body model (HBM), per ANSI/ESDA/JEDEC JS-001 [1]	±400	V

(1) Level listed above is the passing level per ANSI, ESDA, and JEDEC JS-001. JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.

6.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

		MIN	NOM	MAX	UNIT
Supply voltage (VDD-GND)	LM741, LM741A	±10	±15	±22	V
	LM741C	±10	±15	±18	
Temperature	LM741, LM741A	−55		125	°C
	LM741C	0		70	

6.4 Thermal Information

		LM741			
THERMAL METRIC [1]		**LMC (TO-99)**	**NAB (CDIP)**	**P (PDIP)**	**UNIT**
		8 PINS	**8 PINS**	**8 PINS**	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	170	100	100	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	25	—	—	°C/W

(1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application report, SPRA953.

6.5 Electrical Characteristics, LM741[1]

PARAMETER	TEST CONDITIONS		MIN	TYP	MAX	UNIT
Input offset voltage	$R_S \leq 10$ kΩ	$T_A = 25°C$		1	5	mV
		$T_{AMIN} \leq T_A \leq T_{AMAX}$			6	mV
Input offset voltage adjustment range	$T_A = 25°C$, $V_S = \pm20$ V			±15		mV
Input offset current	$T_A = 25°C$			20	200	nA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$			85	500	
Input bias current	$T_A = 25°C$			80	500	nA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$				1.5	µA
Input resistance	$T_A = 25°C$, $V_S = \pm20$ V		0.3	2		MΩ
Input voltage range	$T_{AMIN} \leq T_A \leq T_{AMAX}$		±12	±13		V
Large signal voltage gain	$V_S = \pm15$ V, $V_O = \pm10$ V, $R_L \geq 2$ kΩ	$T_A = 25°C$	50	200		V/mV
		$T_{AMIN} \leq T_A \leq T_{AMAX}$	25			
Output voltage swing	$V_S = \pm15$ V	$R_L \geq 10$ kΩ	±12	±14		V
		$R_L \geq 2$ kΩ	±10	±13		
Output short circuit current	$T_A = 25°C$			25		mA
Common-mode rejection ratio	$R_S \leq 10$ Ω, $V_{CM} = \pm12$ V, $T_{AMIN} \leq T_A \leq T_{AMAX}$		80	95		dB
Supply voltage rejection ratio	$V_S = \pm20$ V to $V_S = \pm5$ V, $R_S \leq 10$ Ω, $T_{AMIN} \leq T_A \leq T_{AMAX}$		86	96		dB
Transient response	Rise time	$T_A = 25°C$, unity gain		0.3		µs
	Overshoot			5%		
Slew rate	$T_A = 25°C$, unity gain			0.5		V/µs
Supply current	$T_A = 25°C$			1.7	2.8	mA
Power consumption	$V_S = \pm15$ V	$T_A = 25°C$		50	85	mW
		$T_A = T_{AMIN}$		60	100	
		$T_A = T_{AMAX}$		45	75	

(1) Unless otherwise specified, these specifications apply for $V_S = \pm15$ V, −55°C ≤ T_A ≤ +125°C (LM741/LM741A). For the LM741C/LM741E, these specifications are limited to 0°C ≤ T_A ≤ +70°C.

6.6 Electrical Characteristics, LM741A[1]

PARAMETER	TEST CONDITIONS		MIN	TYP	MAX	UNIT
Input offset voltage	$R_S \leq 50$ Ω	$T_A = 25°C$		0.8	3	mV
		$T_{AMIN} \leq T_A \leq T_{AMAX}$			4	mV
Average input offset voltage drift					15	µV/°C
Input offset voltage adjustment range	$T_A = 25°C$, $V_S = \pm20$ V		±10			mV
Input offset current	$T_A = 25°C$			3	30	nA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$				70	
Average input offset current drift					0.5	nA/°C
Input bias current	$T_A = 25°C$			30	80	nA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$				0.21	µA
Input resistance	$T_A = 25°C$, $V_S = \pm20$ V		1	6		MΩ
	$T_{AMIN} \leq T_A \leq T_{AMAX}$, $V_S = \pm20$ V		0.5			
Large signal voltage gain	$V_S = \pm20$ V, $V_O = \pm15$ V, $R_L \geq 2$ kΩ	$T_A = 25°C$	50			V/mV
		$T_{AMIN} \leq T_A \leq T_{AMAX}$	32			
	$V_S = \pm5$ V, $V_O = \pm2$ V, $R_L \geq 2$ kΩ, $T_{AMIN} \leq T_A \leq T_{AMAX}$		10			

(1) Unless otherwise specified, these specifications apply for $V_S = \pm15$ V, −55°C ≤ T_A ≤ +125°C (LM741/LM741A). For the LM741C/LM741E, these specifications are limited to 0°C ≤ T_A ≤ +70°C.

Product Folder Links: *LM741*

Electrical Characteristics, LM741A[1] (continued)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
Output voltage swing	$V_S = \pm20$ V	$R_L \geq 10$ kΩ		±16			V
		$R_L \geq 2$ kΩ		±15			
Output short circuit current	$T_A = 25°C$			10	25	35	mA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$			10		40	
Common-mode rejection ratio	$R_S \leq 50$ Ω, $V_{CM} = \pm12$ V, $T_{AMIN} \leq T_A \leq T_{AMAX}$			80	95		dB
Supply voltage rejection ratio	$V_S = \pm20$ V to $V_S = \pm5$ V, $R_S \leq 50$ Ω, $T_{AMIN} \leq T_A \leq T_{AMAX}$			86	96		dB
Transient response	Rise time	$T_A = 25°C$, unity gain			0.25	0.8	µs
	Overshoot				6%	20%	
Bandwidth [2]	$T_A = 25°C$			0.437	1.5		MHz
Slew rate	$T_A = 25°C$, unity gain			0.3	0.7		V/µs
Power consumption	$V_S = \pm20$ V	$T_A = 25°C$			80	150	mW
		$T_A = T_{AMIN}$				165	
		$T_A = T_{AMAX}$				135	

(2)   Calculated value from: BW (MHz) = 0.35/Rise Time (µs).

6.7 Electrical Characteristics, LM741C[1]

| PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
Input offset voltage	$R_S \leq 10$ kΩ	$T_A = 25°C$			2	6	mV
		$T_{AMIN} \leq T_A \leq T_{AMAX}$				7.5	mV
Input offset voltage adjustment range	$T_A = 25°C$, $V_S = \pm20$ V				±15		mV
Input offset current	$T_A = 25°C$				20	200	nA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$					300	
Input bias current	$T_A = 25°C$				80	500	nA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$					0.8	µA
Input resistance	$T_A = 25°C$, $V_S = \pm20$ V			0.3	2		MΩ
Input voltage range	$T_A = 25°C$			±12	±13		V
Large signal voltage gain	$V_S = \pm15$ V, $V_O = \pm10$ V, $R_L \geq 2$ kΩ	$T_A = 25°C$		20	200		V/mV
		$T_{AMIN} \leq T_A \leq T_{AMAX}$		15			
Output voltage swing	$V_S = \pm15$ V	$R_L \geq 10$ kΩ		±12	±14		V
		$R_L \geq 2$ kΩ		±10	±13		
Output short circuit current	$T_A = 25°C$				25		mA
Common-mode rejection ratio	$R_S \leq 10$ kΩ, $V_{CM} = \pm12$ V, $T_{AMIN} \leq T_A \leq T_{AMAX}$			70	90		dB
Supply voltage rejection ratio	$V_S = \pm20$ V to $V_S = \pm5$ V, $R_S \leq 10$ Ω, $T_{AMIN} \leq T_A \leq T_{AMAX}$			77	96		dB
Transient response	Rise time	$T_A = 25°C$, Unity Gain			0.3		µs
	Overshoot				5%		
Slew rate	$T_A = 25°C$, Unity Gain				0.5		V/µs
Supply current	$T_A = 25°C$				1.7	2.8	mA
Power consumption	$V_S = \pm15$ V, $T_A = 25°C$				50	85	mW

(1)   Unless otherwise specified, these specifications apply for $V_S = \pm15$ V, $-55°C \leq T_A \leq +125°C$ (LM741/LM741A). For the LM741C/LM741E, these specifications are limited to $0°C \leq T_A \leq +70°C$.

7 Detailed Description

7.1 Overview

The LM74 devices are general-purpose operational amplifiers which feature improved performance over industry standards like the LM709. It is intended for a wide range of analog applications. The high gain and wide range of operating voltage provide superior performance in integrator, summing amplifier, and general feedback applications. The LM741 can operate with a single or dual power supply voltage. The LM741 devices are direct, plug-in replacements for the 709C, LM201, MC1439, and 748 in most applications.

7.2 Functional Block Diagram
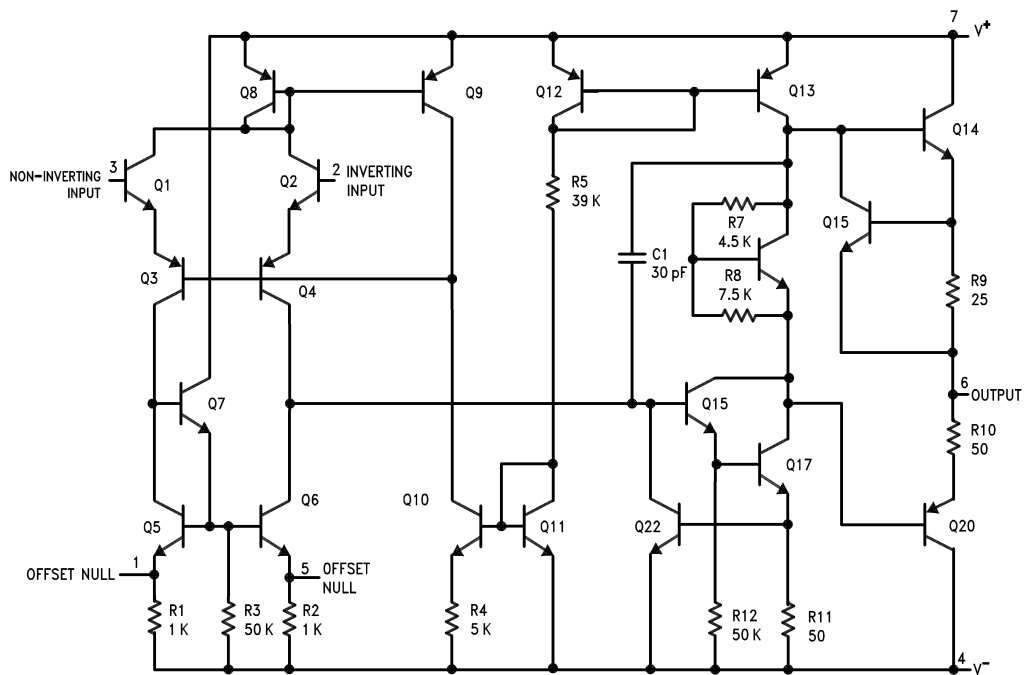
7.3 Feature Description

7.3.1 Overload Protection

The LM741 features overload protection circuitry on the input and output. This prevents possible circuit damage to the device.

7.3.2 Latch-up Prevention

The LM741 is designed so that there is no latch-up occurrence when the common-mode range is exceeded. This allows the device to function properly without having to power cycle the device.

7.3.3 Pin-to-Pin Capability

The LM741 is pin-to-pin direct replacements for the LM709C, LM201, MC1439, and LM748 in most applications. Direct replacement capabilities allows flexibility in design for replacing obsolete parts.

Product Folder Links: *LM741*

7.4 Device Functional Modes

7.4.1 Open-Loop Amplifier

The LM741 can be operated in an open-loop configuration. The magnitude of the open-loop gain is typically large thus for a small difference between the noninverting and inverting input terminals, the amplifier output will be driven near the supply voltage. Without negative feedback, the LM741 can act as a comparator. If the inverting input is held at 0 V, and the input voltage applied to the noninverting input is positive, the output will be positive. If the input voltage applied to the noninverting input is negative, the output will be negative.

7.4.2 Closed-Loop Amplifier

In a closed-loop configuration, negative feedback is used by applying a portion of the output voltage to the inverting input. Unlike the open-loop configuration, closed loop feedback reduces the gain of the circuit. The overall gain and response of the circuit is determined by the feedback network rather than the operational amplifier characteristics. The response of the operational amplifier circuit is characterized by the transfer function.

Product Folder Links: *LM741*

8 Application and Implementation

> **NOTE**
>
> Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

8.1 Application Information

The LM741 is a general-purpose amplifier than can be used in a variety of applications and configurations. One common configuration is in a noninverting amplifier configuration. In this configuration, the output signal is in phase with the input (not inverted as in the inverting amplifier configuration), the input impedance of the amplifier is high, and the output impedance is low. The characteristics of the input and output impedance is beneficial for applications that require isolation between the input and output. No significant loading will occur from the previous stage before the amplifier. The gain of the system is set accordingly so the output signal is a factor larger than the input signal.
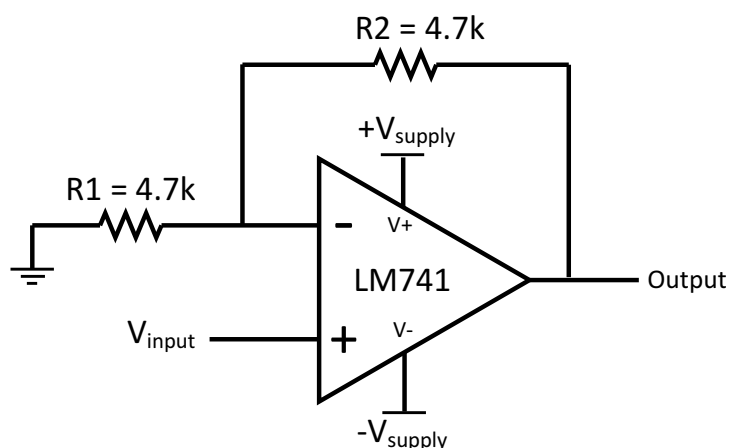
8.2 Typical Application

Figure 1. LM741 Noninverting Amplifier Circuit

8.2.1 Design Requirements

As shown in Figure 1, the signal is applied to the noninverting input of the LM741. The gain of the system is determined by the feedback resistor and input resistor connected to the inverting input. The gain can be calculated by Equation 1:

$$\text{Gain} = 1 + (R2/R1) \tag{1}$$

The gain is set to 2 for this application. R1 and R2 are 4.7-k resistors with 5% tolerance.

8.2.2 Detailed Design Procedure

The LM741 can be operated in either single supply or dual supply. This application is configured for dual supply with the supply rails at ±15 V. The input signal is connected to a function generator. A 1-Vpp, 10-kHz sine wave was used as the signal input. 5% tolerance resistors were used, but if the application requires an accurate gain response, use 1% tolerance resistors.

Typical Application (continued)

8.2.3 Application Curve

The waveforms in Figure 2 show the input and output signals of the LM741 non-inverting amplifier circuit. The blue waveform (top) shows the input signal, while the red waveform (bottom) shows the output signal. The input signal is 1.06 Vpp and the output signal is 1.94 Vpp. With the 4.7-kΩ resistors, the theoretical gain of the system is 2. Due to the 5% tolerance, the gain of the system including the tolerance is 1.992. The gain of the system when measured from the mean amplitude values on the oscilloscope was 1.83.
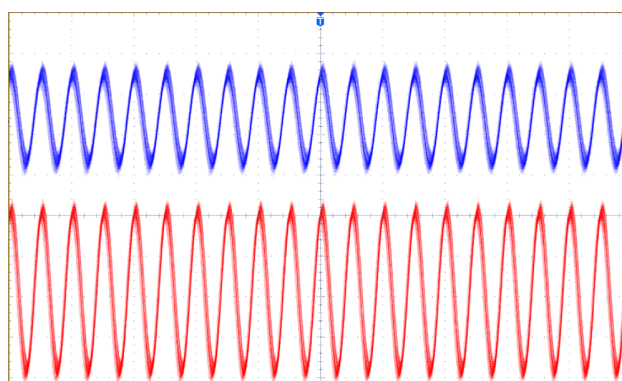
Figure 2. Waveforms for LM741 Noninverting Amplifier Circuit

9 Power Supply Recommendations

For proper operation, the power supplies must be properly decoupled. For decoupling the supply lines, a 0.1-µF capacitor is recommended and should be placed as close as possible to the LM741 power supply pins.

10 Layout

10.1 Layout Guidelines

As with most amplifiers, take care with lead dress, component placement, and supply decoupling in order to ensure stability. For example, resistors from the output to an input should be placed with the body close to the input to minimize pick-up and maximize the frequency of the feedback pole by minimizing the capacitance from the input to ground. As shown in Figure 3, the feedback resistors and the decoupling capacitors are located close to the device to ensure maximum stability and noise performance of the system.

10.2 Layout Example
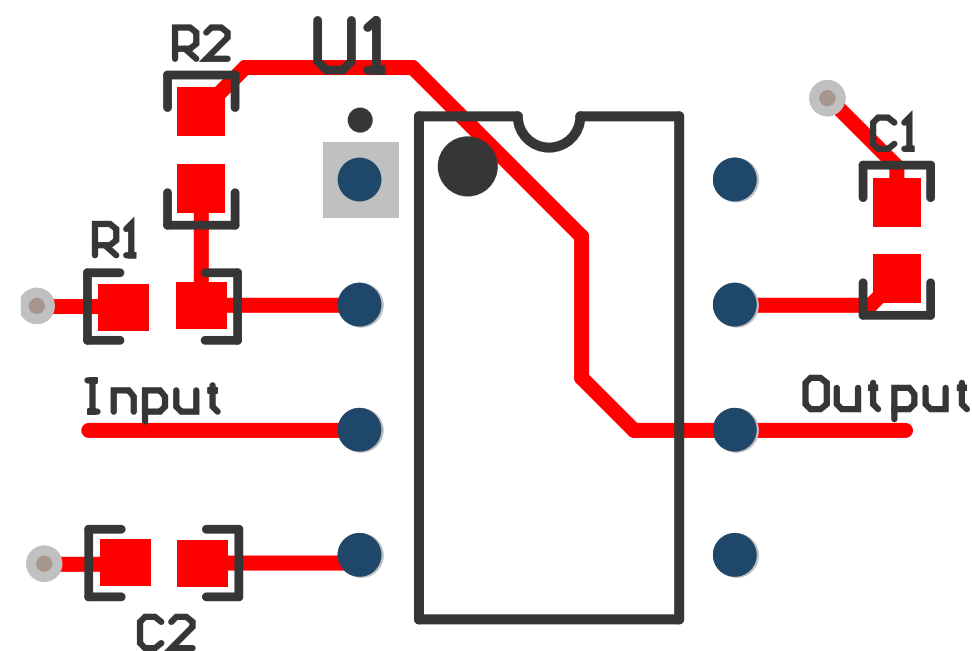
Figure 3. LM741 Layout

11 Device and Documentation Support

11.1 Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

TI E2E™ Online Community *TI's Engineer-to-Engineer (E2E) Community.* Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

Design Support *TI's Design Support* Quickly find helpful E2E forums along with design support tools and contact information for technical support.

11.2 Trademarks

E2E is a trademark of Texas Instruments.
All other trademarks are the property of their respective owners.

11.3 Electrostatic Discharge Caution

These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

11.4 Glossary

SLYZ022 — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

12 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead finish/ Ball material (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
LM741C-MWC	ACTIVE	WAFERSALE	YS	0	1	RoHS & Green	Call TI	Level-1-NA-UNLIM	-40 to 85		Samples
LM741CN/NOPB	ACTIVE	PDIP	P	8	40	RoHS & Green	NIPDAU	Level-1-NA-UNLIM	0 to 70	LM 741CN	Samples

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) RoHS: TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead finish/Ball material - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

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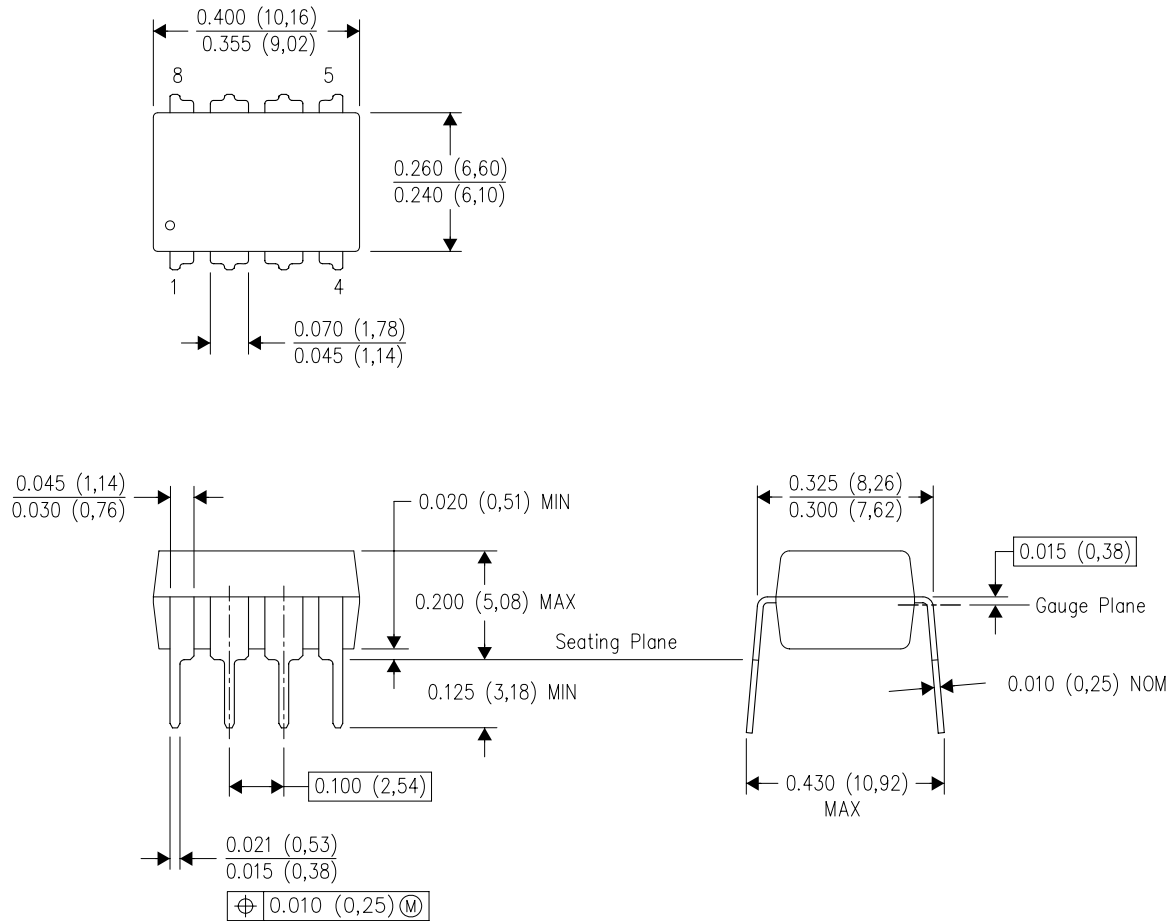
PACKAGE MATERIALS INFORMATION

TUBE
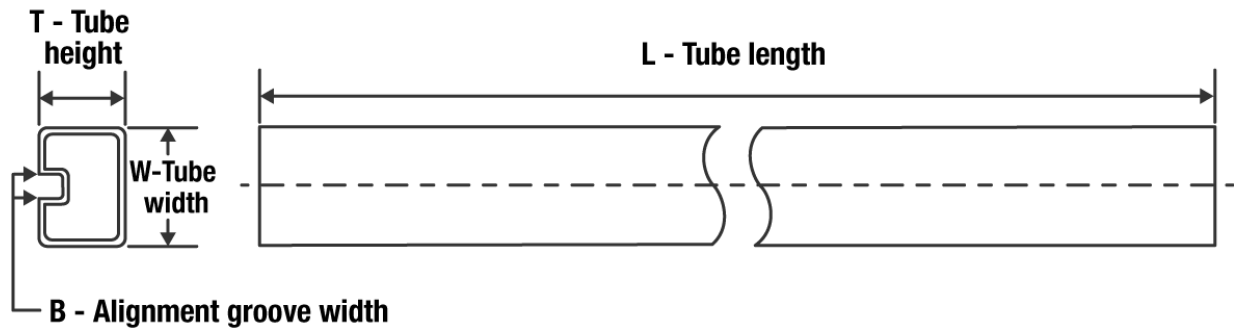
*All dimensions are nominal

Device	Package Name	Package Type	Pins	SPQ	L (mm)	W (mm)	T (µm)	B (mm)
LM741CN/NOPB	P	PDIP	8	40	502	14	11938	4.32

P (R−PDIP−T8)   PLASTIC DUAL−IN−LINE PACKAGE

0.400 (10,16)
0.355 (9,02)

8   5

0.260 (6,60)
0.240 (6,10)

1   4

0.070 (1,78)
0.045 (1,14)

0.045 (1,14)
0.030 (0,76)

0.020 (0,51) MIN

0.200 (5,08) MAX

Seating Plane

0.125 (3,18) MIN

0.100 (2,54)

0.021 (0,53)
0.015 (0,38)

⊕ 0.010 (0,25) Ⓜ

0.325 (8,26)
0.300 (7,62)

0.015 (0,38)

Gauge Plane

0.010 (0,25) NOM

0.430 (10,92)
MAX

4040082/E 04/2010

NOTES: A.   All linear dimensions are in inches (millimeters).
         B.   This drawing is subject to change without notice.
         C.   Falls within JEDEC MS−001 variation BA.

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